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APPARATUS FOR DISPLAYING MULTIPLE SERIES OF IMAGES TO VIEWERS IN MOTION

Cross Reference to Related Application

This claims the benefit of United States Provisional Patent Application No. 60/158,906, filed October 12, 1999.

Background of the Invention

This invention relates to the display of still images that appear animated to a viewer in motion relative to those images. More particularly, this invention relates to the display of multiple series of still images in which each series appears animated to a viewer in motion relative to the still images.

Display devices that display still images appearing to be animated to a viewer in motion are known. These devices include a series of graduated images (i.e., adjacent images that differ slightly and progressively from one to the next). The images are arranged in the direction of motion of a viewer (e.g., along a railroad) such that the images are viewed consecutively. As a viewer moves past these images, they appear animated. The effect is similar to that of a flip-book. A flip-book has an image on each page that differs slightly from the one before it and the one after it such that when the pages are flipped, a viewer perceives animation.

A longstanding trend in mass transportation systems has been the development of installations to provide the passengers in subway systems with animated motion pictures. The animation of these motion pictures is effected by the motion of the viewer relative to the installation, which is fixed to the tunnel walls of the subway system. Such installations have obvious value: the moving picture is viewable through the train windows, through which only darkness would otherwise be visible. Possible useful moving picture subjects could be selections of artistic value, or informative messages from the transportation system or from an advertiser.

Each of the known arrangements provides for the presentation of a series of graduated images, or "frames," to the viewer/rider so that consecutive frames are viewed one after the other. As is well known, the simple presentation of a series of still images to a moving viewer is perceived as nothing more than a blur if displayed too close to the viewer at a fast rate. Alternatively, at a large distance or low speeds, the viewer sees a series of individual images with no animation. In order to achieve a motion picture effect, known arrangements have introduced methods of displaying each image for extremely short periods of time. With display times of sufficiently short duration, the relative motion between viewer and image is effectively arrested, and blurring is negligible. Methods for arresting the motion have been based on stroboscopic illumination of the images. These methods require precise synchronization between the viewer and the installation in order that each image is illuminated at the same position relative to the viewer, even as the viewer moves at high speed.

The requirements of a stroboscopic device are numerous: the flash must be extremely brief for a fast

moving viewer, and therefore correspondingly bright in order that enough light reach the viewer. This requirement, in turn, requires extremely precisely timed flashes. This precision requires extremely consistent motion on the part of the viewer, with little or no change in speed. All of the aforementioned requirements result in a high level of mechanical or electrical complexity and cost, or greater consistency in train motion than exists. Other known arrangements have overcome the need for high temporal precision by providing a transponder of some sort on the viewer's vehicle and a receiver on the installation to determine the viewer's position. These arrangements involve considerable mechanical and electrical complexity and cost.

The aforementioned known arrangements generally require the viewer to be in a vehicle. This requirement may be imposed because the vehicle carries equipment for timing, lighting, or signaling; or because of the need to maintain high consistency in speed; or to increase the viewer's speed, for example. The use of a vehicle requires a high level of complexity of the design because of the number of mechanical elements and because one frequently is dealing with existing systems, requiring modification of existing equipment. The harsh environment of being mounted on a moving subway car may limit the mechanical or electrical precision attainable in any unit that requires it, or it may require frequent maintenance for a part where high precision has been attained.

The use of a vehicle also imposes constraints. At the most basic level, it limits the range of possible applications to those where viewers are on vehicles. More specifically, considerations of the vehicle's physical dimensions constrain a stroboscopic device's applicability. The design must

take into account such information as the vehicle's height and width, its window size and spacing, and the positions of viewers within the vehicle. For example, close spacing of windows on a high speed train requires that stroboscopic discharges preferably be of high frequency and number in order that the display be visible to all occupants of a train. The dimensions of the environment, such as the physical space available for hardware installation in the subway tunnel and the distances available over which to project images, impose further constraints on the size of elements of any device as well as on the quality and durability of its various parts.

Though in principle a stroboscopic device can work for slowly moving viewers, simply by spacing the projectors more closely, in practice it is difficult. First, closer spacing increases cost and complexity. Also, once the device is installed with a fixed projector-to-projector distance, a minimum speed is imposed on the viewer.

An existing method for the display of animated images involving relative motion between the viewer and the device is the zootrope. The zootrope is a simple hollow cylindrical device that produces animation by way of the geometrical arrangement of slits cut in the cylinder walls and a series of graduated images placed on the inside of the cylinder, one per slit. When the cylinder is spun on its axis, the animation is visible through the (now quickly moving) slits.

The zootrope is, however, fixed in nearly all its proportions because its cross section must be circular. Since the animation requires a minimum frame rate, and the frame rate depends on the rotational speed, only a very short animation can be viewed using a zootrope. Although there is relative motion between

the viewer and the apparatus, in practice the viewer cannot comfortably move in a circle around the zootrope. Therefore only one configuration is practicable with a zootrope: that in which a stationary viewer observes a short animation through a rotating cylinder.

For the reasons of its incapacity to be altered in shape, the short duration of its animation, and the fact that it must be spun, the zootrope has remained a toy or curiosity without practical application. However, at least one known system displays images along an outdoor railroad track in an arrangement that might be referred to as a "linear zootrope" in which the images are mounted behind a wall in which slits are provided. That outdoor environment is essentially unconstrained.

In view of the foregoing, it would be desirable to provide apparatus for use in a spatially-constrained environment that displays still images that appear animated to a viewer in motion.

It would also be desirable to provide such apparatus for use in a spatially-constrained environment having known ambient lighting levels.

It would further be desirable to provide such apparatus that displays multiple series of still images such that each series appears animated to a viewer in motion.

<u>Summary of the Invention</u>

It is an object of this invention to provide apparatus for use in a spatially-constrained environment that displays still images that appear animated to a viewer in motion.

It is also an object of this invention to provide such apparatus for use in a spatially-

constrained environment having known ambient lighting levels.

It is further an object of this invention to provide such apparatus that displays multiple series of still images such that each series appears animated to a viewer in motion.

In accordance with this invention, apparatus is provided that displays multiple series of still images. Each series of still images forms an animated display to a viewer moving substantially at a known velocity relative to the images substantially along a known trajectory substantially parallel to the images. The apparatus includes a backboard having a backboard length along the trajectory. Images of each series are interspersed with images of other series and are mounted on a surface of the backboard. Each still image has an actual image width and an image center. Image centers of successive images of the same series are separated by a frame-to-frame distance. A slitboard is positioned substantially parallel to the backboard facing the surface upon which the images are mounted and is separated therefrom by a board-to-board distance. The slitboard is mounted at a viewing distance from the trajectory. The board-to-board distance and the viewing distance total a backboard distance. The slitboard has a slitboard length along the trajectory and has a plurality of slits substantially perpendicular to the slitboard length. Each slit corresponds to a respective image of each series and has a slit width measured along the slitboard length and a slit center. Respective slit centers of adjacent slits are preferably separated by the frame-to-frame distance.

Each series of still images can be viewed from a respective viewing angle relative to a viewer moving along the known trajectory. The multiple series

of still images can be arranged such that each series can be viewed while moving in the same direction along the known trajectory. Or, alternatively, the multiple series of still images can be arranged such that one or more series can be viewed while moving in one direction along the known trajectory, while one or more other series can be viewed while moving in the opposite direction along the known trajectory.

Brief Description of the Drawings

The above and other objects and advantages of the invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

FIG. 1 is a perspective view of a illustrative embodiment of apparatus according to the present invention;

FIG. 2 is an exploded perspective view of the apparatus of FIG. 1;

FIG. 2A is a perspective view of an alternative illustrative embodiment of the apparatus of FIGS. 1 and 2;

FIG. 3 is a schematic diagram of the geometry and optics of the apparatus of FIGS. 1 and 2;

FIG. 3A is a schematic diagram of the geometry of a curved embodiment of the invention;

FIGS. 4A, 4B and 4C (collectively "FIG. 4") are schematic representations of a single image and slit with a viewer at three different positions at three different instants of time;

FIGS. 5A, 5B and 5C (collectively "FIG. 5") are schematic representations of a pair of images and slits with a viewer at three different positions at three different instants of time;

FIG. 6 is a schematic representation of a single image being viewed by a viewer over time, illustrating the stretching effect;

FIG. 6A is a schematic representation illustrating the stretching effect where the backboard is not parallel to the direction of motion;

FIG. 7 is a schematic plan view of second illustrative embodiment of the invention wherein the images are curved;

FIG. 8 is a schematic plan view of a third illustrative embodiment of the invention wherein the images are inclined relative to the backboard;

FIG. 9 is a schematic plan view of a fourth illustrative embodiment of the invention, similar to the embodiment of FIG. 8, but wherein the slitboard includes a series of sections parallel to the images and inclined relative to the backboard;

FIG. 10 is a schematic perspective representation of a pair of combination slitboard/ backboards from a fifth illustrative embodiment of the invention which is two-sided;

FIG. 11 is a schematic plan view of the embodiment of FIG. 10;

FIG. 12 is a schematic plan view of a sixth embodiment having curved images such as in the embodiment of FIG. 7, and being two-sided such as in the embodiment of FIGS. 10 and 11;

FIG. 13 is a perspective view of a roller-type image holder for use in a seventh illustrative embodiment of the invention;

FIG. 14 is a perspective view of an eighth illustrative embodiment of the invention;

FIG. 15 is a vertical cross-sectional view, taken from line 15-15 of FIG. 14, of the eighth illustrative embodiment of the invention;

FIG. 16 is a simplified perspective view showing the mounting of a plurality of modular units according the invention in a subway tunnel;

FIG. 17 is a perspective view of a preferred embodiment of a single-unit of apparatus having multiple series of images according to the present invention;

FIGS. 18 and 19 are schematic plan views illustrating directions of pedestrian travel and lines of sight along a pedestrian walkway adjacent apparatus of the present invention;

FIG. 20 is a schematic plan view of the apparatus of FIG. 17;

FIG. 21 is a schematic plan view of another preferred embodiment of a single-unit of apparatus according to the present invention;

FIG. 22 is a schematic plan view of a preferred embodiment of a section of apparatus according to the present invention;

FIG. 23 is a schematic plan view of another preferred embodiment of a section of apparatus according to the present invention;

FIG. 24 is a schematic plan view of a preferred embodiment of a section of apparatus having spaced apart images according to the present invention;

FIG. 25 is a schematic plan view illustrating another line of sight for the apparatus of FIG. 23;

FIGS. 26 and 27 are schematic plan views illustrating ranges of lines of sight in a section of apparatus according to the present invention;

FIG. 28 is a schematic plan view of an exemplary embodiment of a section of apparatus using opaque elements according to the present invention;

FIG. 29 is a schematic plan view of a preferred embodiment of a section of apparatus using baffles according to the present invention;

FIG. 30 is a schematic plan view of the apparatus of FIG. 23 using baffles according to the present invention;

FIG. 31 is a schematic plan view of a preferred embodiment of a section of apparatus using T-baffles according to the present invention;

FIGS. 32A-B are schematic plan views of the apparatus of FIG. 23 using T-baffles according to the present invention; and

FIG. 33 is a schematic plan view of a preferred embodiment of a section of apparatus using light sources according to the present invention.

Detailed Description of the Invention

The present invention preferably produces simple apparatus operating on principles of simple geometric optics that displays animation to a viewer in motion relative to it. The apparatus requires substantially only that the viewer move in a substantially predictable path at a substantially predictable speed. There are many common instances that meet this criterion, including, but not limited to, riders on subway trains, pedestrian on walkways or sidewalks, passengers on surface trains, passengers in motor vehicles, passengers in elevators, and so on. For the remainder of this document, for ease of description, reference will primarily be made to a particular exemplary application -- an installation in a subway system, viewable by riders on a subway train -- but the present invention is not limited to such an application.

Benefits of the present invention include the following:

1. A viewer preferably does not need to be in a vehicle.

2. Complex stroboscopic illumination is preferably not needed.
3. Precise timing or positioning triggers between the apparatus and the viewer are preferably not needed.
4. Moving parts are preferably not needed.
5. Preferably, no shutter is required.
6. Preferably, no special equipment mounted on the viewer or the viewer's vehicle, if the viewer is in a vehicle, is required.
7. Preferably, no transfer of information between the apparatus and the viewer pertaining to the viewer's position, speed or direction of motion is needed.
8. A very high depth of field of viewability is preferably offered.
9. It can be designed to operate independently of the direction of a viewer's motion.
10. It preferably is effective for each member of a closely spaced series of viewers, independent of their spacing or relative motions.
11. It preferably requires no optics more precise than a simple slit (although other optics may be used).
12. It preferably requires no correlation between vehicle window spacing and picture spacing.
13. It preferably offers the possibility of effective magnification of the image in the direction of motion.
14. It preferably requires very low minimum viewer speed because the magnification

allows very close spacing of graduated images.

15. It preferably does not require a particular geometry, be it circular, linear, or any other geometry.

16. It preferably has no maximum speed.

The apparatus preferably includes a series of graduated pictures ("images" or "frames") spaced at preferably regular intervals and, preferably between the pictures and the viewer, an optical arrangement that preferably restricts the viewer's view to a thin strip of each picture. This optical arrangement preferably is an opaque material with a series of thin, transparent slits in it, oriented with the long dimension of the slit perpendicular to the direction of the viewer's motion. The series of pictures will generally be called a "backboard" and the preferred optical arrangement will generally be called a "slitboard."

Not essential to the invention, but often desirable, is a source of illumination so that the pictures are brighter than the viewer's environment. The illumination can back-light the pictures or can be placed between the slitboard and backboard to front-light the pictures substantially without illuminating the viewer's environment. When lighting is used it preferably should be constant in brightness. Natural or ambient light can be used. If ambient light is sufficient, the apparatus can be operated without any built-in source of illumination.

Also not necessary, but often desirable, is to make the viewer side of the slitboard dark or nonreflecting, or both, in order to maximize the contrast between the pictures viewable through the slitboard and the slitboard itself. However, the slitboard need not necessarily be dark or

nonreflective. For example, the viewer face of the slitboard could have a conventional billboard placed on it with slits cut at the desired positions. This configuration is particularly useful in places where some viewers are moving relative to the device and others are stationary. This may occur, for example, at a subway station where an express train passes through without stopping, but passengers waiting for a local train stand on the platform. The moving viewers preferably will see the animation through the imperceptible blur of the conventional billboard on the slitboard front. The stationary viewers preferably will see only the conventional billboard.

The invention will now be described with reference to FIGS. 1-16.

The basic construction of a preferred embodiment of a display apparatus 10 according to the present invention is shown in FIGS. 1 and 2. In this embodiment, apparatus 10 is essentially a rectangular solid formed by housing 20 and lid 21. The front and rear of apparatus 10 preferably are formed by slitboard 22 and backboard 23, which are described in more detail below. Slitboard 22 and backboard 23 preferably fit into slots 24 in housing 20 which are provided for that purpose. Lightframe 25 preferably is interposed between housing 20 and lid 21 and preferably encloses light source 26, which preferably includes two fluorescent tubes 27, to light images, or "frames" 230, on backboard 23. Slitboard 22 preferably includes a plurality of slits 220 as described in more detail below. Preferably, in order to keep foreign matter out of apparatus 10, particularly if it is to be used in a harsh or dirty environment such as a subway tunnel, each slit 220 is covered by a light-transmissive, preferably transparent cover 221 (only one shown). Alternatively, each slit 220 may be covered by a

semicylindrical lens 222 (only one shown), which also improves the resolution of viewed images. Specifically, if the focal length of the lens is approximately equal to the distance between slitboard 22 and backboard 23, the resolution of the image may be increased. This improvement of the resolution is effected by narrowing the width of the sliver of the actual image visible at a given instant by the viewer. Alternatively, the use of lenses may allow the slit width to be increased without lowering resolution.

In an alternative embodiment 200, shown in FIG. 2A, housing 201 is similar to housing 20, except that it includes light-transmissive, preferably transparent, front and rear walls 202, 203 respectively, forming a completely enclosed structure. At least one of walls 202, 203 (as shown, it is wall 202) preferably is hinged as at 204 to form a maintenance door 205 which may be opened, e.g., to replace backboard 23 (to change the images 230 thereon) or to change light bulbs 27). As shown in FIG. 2A, light bulbs 27 are provided in a backlight unit 206 instead of lightframe 25, necessitating that backboard 23 and images 230 be light-transmissive. Of course, embodiment 200 could be used with lightframe 25 instead of backlight unit 206. Similarly, apparatus 10 could be provided with backlight unit 206 instead of lightframe 25, in which case backboard 23 and images 230 would be light-transmissive.

FIG. 3 is a schematic plan view of a portion of apparatus 10 being observed by a viewer 30 moving at a substantially constant velocity V_w along a track 31 substantially parallel to apparatus 10. Track 31 is drawn as a schematic representation of a railroad track, but may be any known trajectory such as a highway, or a walkway or sidewalk, on which viewers

move substantially at a known substantially constant velocity.

The following variables may be defined from FIG. 3:

D_s = slit width

D_{ff} = frame-to-frame distance

D_{bs} = backboard-to-slitboard distance

V_w = speed of viewer relative to apparatus

D_{sb} = thickness of slitboard

D_i = actual width of a single image frame

D_{vs} = distance from viewer to slitboard

Other parameters, which are not labeled, will be described below, including B (brightness), c (contrast), and D_i' (apparent or perceived width of a single image frame).

An alternative geometry is shown in FIG. 3A, where track 31' is curved, and slitboard 22' and backboard 23' are correspondingly curved, so that all three are substantially "parallel" to one another. Although not labeled in FIG. 3A, the other parameters are the same as in FIG. 3, except that, depending on the degree of curvature, there may be some adjustment in the amount of stretching or enlargement of the image as discussed below.

One of the most significant departures of the present invention from previously known apparatus designed to be viewed from a moving vehicle is that no attempt is made to arrest the apparent motion of the image. That is, in the present device the image is always in motion relative to the viewer, and some part of the image is always viewable by the viewer. This contrasts with known systems for moving viewers where a stroboscopic flash is designed to be as close as instantaneous as possible in order to achieve an apparent cessation of motion of an individual image frame, despite its true motion relative to the viewer.

As with all animation, the apparatus according to the invention relies on the well known effect of persistence of vision, whereby a viewer perceives a continuous moving image when shown a series of discrete images. The operation of the invention uses two distinct, but simultaneous, manifestations of persistence of vision. The first occurs in the eye reconstructing a full coherent image, apparently entirely visible at once, when actually shown a small sliver of the image that sweeps over the whole image. The second is the usual effect of the flip-book, whereby a series of graduated images is perceived to be a continuous animation.

FIG. 4 illustrates the first persistence of vision effect. It shows the position of viewer 30 relative to one image at successive points (FIGS. 4A, 4B, 4C) in time. In each of FIGS. 4A, 4B and 4C, double-ended arrow 40 represents the total actual image width, D_i, while distance 41 represents the portion of the image visible at a given time. This diagram shows that viewer 30, over a short period of time, gets to see each part of the image. However, at any given instant only a thin sliver of the picture, of width 41, is visible. Because the period of time over which the sliver is visible is very short, and therefore the motion of the image viewed through the slit in that time is very small, the viewer perceives very little or no blur, even at very high speeds. There is no theoretical upper limit on the speed at which the apparatus works -- the faster the viewer moves, the less time a given sliver is visible. That is, the effect that would cause blur -- the viewer's increased speed -- is canceled by effect that reduces blur -- the period of viewability of a given sliver.

In FIG. 4 the representation of movement of the viewer's eye is purely illustrative. In practice

the viewer's gaze is fixed at a screen that is perceived to be stationary, and the entirety of the frame can be seen through peripheral vision, as with a conventional billboard.

FIG. 5 illustrates the second persistence of vision effect. It shows viewer 30 looking in a fixed direction at three successive points in time. In FIG. 5A, a thin sliver of a first image n is in the direct line of the viewer's gaze through slit 221. In FIG. 5B, the viewer's direct gaze falls on a blocking part of slitboard 22. For the duration that the opaque part of slitboard 22 is in the line of the viewer's direct gaze, the viewer continues to perceive the sliver of image n just seen through slit 221. In FIG. 5C, the direct line of the viewer's gaze falls on slit 222, adjacent to slit 221, and viewer 30 sees a sliver of adjacent image n+1. Because each slit 221, 222 preferably is substantially perfectly aligned with its respective image, the slivers visible at a given angle in the two separate slots preferably correspond substantially precisely. That is, at a position, say, three inches from the left edge of the picture, the sliver three inches from the left edge of the picture is viewable from one frame to the next, and never a sliver from any other part of the image. In this way, the alignment between the slit and the image prevents the confusion and blur perceived by the viewer that otherwise would be caused by the fast motion of the images. Because successive frames differ slightly as with successive images in conventional animations, the viewer perceives animation.

The two persistence of vision effects operate simultaneously in practice. Above a minimum threshold speed, viewer 30 perceives neither discrete images nor discrete slivers.

A very useful effect of apparatus 10 is the apparent stretching, or widening, of the image in the direction of motion. FIG. 6 illustrates the geometrical considerations explaining this stretching effect. Labeled "Position 1" and "Position 2" are the two positions of a given frame 230 where the opposite edges of frame 230 are visible. Because the positions of frame 230 and slit 220 are fixed relative to each other, they precisely determine the angle at which viewer 30 must look in order that slit 220 be aligned with an edge of the image 230.

At Position 1, the left edge of image 230 is aligned with slit 220 and the viewer's eye. At Position 2, the right edge of image 230 is aligned with slit 220 and the viewer's eye. In fact, the two positions occur at different times, but, as explained above, this is not observed by the viewer 30. Only one full image is observed.

If x is the distance from the centerpoint between the two positions of slit 220 to either of the individual positions at Position 1 or Position 2, then the perceived width of the image, D_i', is 2x. By similar triangles,

$$D_{vs}/x = (D_{vs}+D_{bs})/(x+D_i/2)$$

$$x(D_{vs}+D_{bs}) = (x+D_i/2)D_{vs}$$

$$2x = (D_{vs}/D_{bs})D_i$$

$$D_i' = (D_{vs}/D_{bs})D_i \qquad (1)$$

Thus the perceived width of the image, D_i', is increased over the actual width of the image by a factor of the ratio of the viewer-slitboard distance to the slitboard-backboard distance.

FIG. 6A shows the magnification effect when the backboard 23' is not substantially parallel to the viewer's trajectory. The magnification is found by defining a formula f(x), where x is the distance along the viewer's trajectory, for the shape of the

backboard -- that is, the distance of the backboard from the axis defined by the viewer's trajectory -- around each slit (for example, FIG. 7 shows a backboard 71 on which each image 730 forms a semicircle around its respective slit 220). For ease of convention, one can define an x axis along the direction of the viewer's motion and a y axis perpendicular to the x axis and choose the origin at the position of the viewer 30.

To find the magnification, one determines how an arbitrary picture element 230' on the backboard 23' will appear to viewer 30 on a projected flat backboard 23". In FIG. 6A, a section of the true backboard 23' is shown between slitboard 22 and the projected backboard 23". A length PR of the backboard 23' defines a picture element 230'. This section 230' will appear to viewer 30 as if on projected flat backboard 23", as indicated.

For ease of presentation, the section of backboard 23' shown is a straight line segment, but this linearity is not required. Also, the backboard shape does not need to be perfectly described by a formula $y=f(x)$. In practice one can approximate the backboard's true shape in a number of ways -- for example, by treating the backboard as a series of infinitesimal elements, each of which can be approximated by a line segment.

Viewer 30, at position A, sees the left edge P of picture element 230' when slit 220 is at Q. Because the positions of picture element 230' and slit 220 are fixed relative to each other, they precisely determine the angle at which viewer 30 must look in order that slit 220 be aligned with an edge of the element 230'. Therefore, the right edge R of this picture element 230' will be visible when the device

has moved relative to viewer 30 to a position where a line parallel to QR passes through A.

The left edge of picture element 230' will appear on projected backboard 23" at position B, a distance Δx from the y axis. The right edge of picture element 230' will appear on projected backboard 23" at position C. The apparent width of the image, D_i', is the distance BC.

Point P is the intersection of backboard 23' with the line through A and B.

Point Q is the intersection of slitboard 22 with the line through A and B.

Point R is the intersection of backboard 23' with the line through Q and R.

The distance D_i is the distance from P to R.

The coordinates of the point P, (P_x, P_y), are the solution (x,y) to $y=f(x)$ and

$$y=(D_{vb}/\Delta x)x, \tag{A}$$

where the latter equation is the formula for the line through A and B.

The coordinates of point Q, (Q_x, Q_y), are the solution (x,y) to $y=(D_{vb}/\Delta x)x$, and

$$y=D_{bs}. \tag{B}$$

The coordinates of point R, (R_x, R_y), are the solution (x,y) to $y=f(x)$ and

$$y-Q_y=((\Delta x+D_i')/D_{vb})(x-Q_x). \tag{C}$$

Finally, the size D_i that picture element 230' should have in order that it stretch to size D_i' is given by

$$D_i=((R_x-P_x)^2+(R_y-P_y)^2)^{0.5}, \tag{D}$$

where the variables on the right hand side can all be found in terms of dimensions of the apparatus and Δx.

The above derivations demonstrate practical methods for determining the stretching effect in order to preshrink an image for either substantially parallel or nonparallel backboards. A useful rule of thumb

which is true for either backboard configuration comes from the fact that angle BAC is equal to angle BQR -- the angular size of the projected image as seen by the viewer is the same as the angular size of the actual image at the position of slit 220.

In order to preshrink an image, it can be divided into many elements, starting at $\Delta x=0$ and moving sequentially in either direction while incrementing Δx appropriately. Then each element can be preshrunk and placed at the appropriate location on the backboard.

In cases where the viewer's trajectory is curved, such as the geometry shown in FIG. 3A, neither the slitboard nor the backboard will necessarily be a straight line. A similar derivation can be used to the one for nonparallel backboards, by defining a function $g(x)$ for the path of the slit relative to the viewer and replacing Relation (B) with $y=g(x)$.

In practice, the images may be shrunk in the direction of motion before being mounted on the backboard in order that when projected they are stretched to their proper proportions, allowing a large image to be presented in a relatively smaller space. Curved or inclined surfaces on the backboard can be used to augment the effect. That is, as a non-planar backboard approaches the slitboard, the magnification increases greatly. However, for simplicity, the discussion that follows will assume a planar backboard unless otherwise indicated.

As shown below, the stretching effect, when adjusted through the relevant variable parameters of apparatus 10, can be very useful. Also, the relation between the perceived image size, D_i', and the viewer distance, D_{vs}, is linear -- the image gets bigger as the viewer moves farther away. This can be a useful effect in the right environment.

There are some limitations and side effects. Both effects of persistence of vision require minimum speeds that are not necessarily equal. Too slow a speed can result in the appearance of only discrete vertical lines, or flicker, or a lack of observed animation effect. In practice, the appearance of only discrete vertical lines is the dominant limitation. A possibly useful effect of the stretching effect arises from the fact that slivers of multiple frames are visible at the same time. That is, if the perceived image is ten times larger than the true image, slivers of ten different images may be visible at any given time. Because each frame presents a different point in time in the animation, multiple times of the image may be simultaneously viewable. This effect may, for example, be used to interlace images, if desired. Similarly, multiple instances of a single frame can be displayed, in a manner similar to that used in commercial motion picture projection. Alternatively, the effect can also result in confusion or blur perceived by viewer 30. In practice this confusion is barely noticeable, however, and can be reduced through a higher frame rate or a slower varying subject of animation.

Another possibly useful effect occurs when the image of one frame 230 is visible through the slit 220 corresponding to an adjacent frame 230. In this case, multiple side-by-side animations may be visible to the viewer. These "second-order" images can be used for graphic effect, if desired. Or, if not desired, they may be removed by increasing slitboard thickness D_{sb} or the ratio D_{ff}/D_i, by introducing a light baffle 32 between slitboard 22 and backboard 23, or by altering the geometry of backboard 23. All of these techniques are described below.

Still another possibly useful effect arises from the fact that the stretching effect distorts the proportions of image 230. One can remove this effect, if not desired, by preshrinking the images 230 so that the stretching effect restores the true proportions. Care must be taken, however, in the case where different viewers 30 observe apparatus 10, each from a different D_{vs}. In this case, the exact restoration to perfect dimensions occurs at one D_{vs} only. At another D_{vs}, the restoration is not exact. In practice, however, for many useful ranges of parameters, the improper proportions have few or no adverse effects.

In general, four parameters are imposed by the environment -- V_w, D_{bs}, D_{vs}, and D_i'. V_w, the viewer's speed, is generally imposed by, e.g., the speed of the vehicle, typical viewer footspeed, or the speed of a moving walkway, escalator, etc. D_{bs}, the backboard-to-slitboard distance, is generally limited by the space between a train and the tunnel wall, or the available space of a pedestrian walkway, for example. D_{vs}, the distance from viewer to slitboard, is imposed by, for example, the width of a subway car or the width of a pedestrian walkway. Finally, D_i', the perceived image width, should be no larger than the area visible to viewer 30 at a given instant -- for example, the width of a train window.

Also generally imposed is the well-established minimum frame rate for the successful perception of the animation effect -- viz., approximately 15-20 frames per second. The frame rate, the frame-to-frame distance, and viewer speed are related by

$$\text{Frame rate} = V_w/D_{ff} \qquad (2)$$

Because the frame rate must generally be greater than the minimum threshold, and V_w is generally imposed by the environment, this relation sets a maximum D_{ff}.

For example, for a train moving at about 30 miles per hour (about 48 kilometers per hour), given a minimum frame rate of about 20 frames per second, the relation above determines that D_{ff} can be as great as about 2 feet (about 67 cm).

Alternatively, the minimum V_w is determined by the minimum D_{ff} allowable by the image, which is constrained by the fact that D_{ff} can be no smaller than D_i. The stretching effect theoretically allows D_i to be lowered arbitrarily without lowering D_i', because D_{bs} can, in principle, be lowered arbitrarily. In practice, however, D_{bs} cannot be lowered arbitrarily, because very small values result in very different perceived image widths for each viewer 30 at a different D_{vs}. That is, at too small a D_{bs}, viewers on opposite sides of a train could see too markedly differently proportioned images. Moreover, small D_{bs}, resulting in high magnification, requires correspondingly high image quality or printing resolution.

If viewers at different distances D_{vs} will observe apparatus 10, the closest ones (those with the smallest D_{vs}) generally determine the limits on D_{bs}.

Because images cannot overlap,

$$D_i \leq D_{ff}. \tag{3}$$

If $D_i = D_{ff}$ and one can view second order images, they will appear to abut the first order image, slightly out of synchronization. The resulting appearance will be like that of multiple television sets next to each other and starting their programs at slightly different times. This effect may be used for graphic intent, or, if not desired, three variations in parameters can remove it.

First, one can decrease the ratio D_i/D_{ff}, effectively putting space between adjacent images.

This change will send second order images away from the primary ones.

Second, one may increase slitboard thickness D_{sb} so that second order images are obscured by the cutoff angle. That is, for any non-zero thickness of slitboard 22, there will be an angle through which if one looks one will not be able to see through the slits. As the thickness of slitboard 22 increases, this angle gets smaller, and can be seen to follow the relation

$$D_{sb}/D_s \leq D_{bs}/(D_i/2) \tag{4}$$

This relation may alternatively be written

$$D_{sb}/D_s \leq D_{vs}/(D_i'/2) \tag{5}$$

by substitution for D_i' from Relation 1. This shows the limit on D_{sb} imposed by the desired perceived image width.

The same effect as described in the preceding paragraph can be achieved by placing light baffle 32 between slitboard 22 and backboard 23, thereby obstructing the view of one image 230 through the slit 220 of an adjacent image 230.

Third, one can change the shape of the backboard, as illustrated in FIG. 7. In apparatus 70, backboard 71 bears curved images 730 so that second order images are not observed. The change in backboard shape will result in a slightly altered stretching effect. As before, this stretching effect can be undone by preshrinking the image in the direction of motion.

The embodiment illustrated in FIG. 7 has the potentially useful property not only of showing no second order images, but also of an arbitrarily wide first order image. This effect is related to, but distinct from, the stretching effect described above, which assumes a flat backboard geometry. The final observed width of the image is limited by the

vignetting of the slitboard -- the exact relation can be found by solving Relation 5 for D_i'. It can be observed from FIG. 7 that as the viewing angle becomes large, the viewer continues to observe through each given slit 220 only the image 730 corresponding to that slit 220. In the ideal limit of zero slitboard width, the leftmost sliver of the image is viewable when the viewer looks 90° to the left and the rightmost sliver is viewable when the viewer looks 90° to the right. The slivers in between are continuously viewable between these extreme angles. In other words, each image is observed as infinitely wide. (In FIG. 7, the curved image 730 does not quite reach the slitboard 22, in order to illustrate the maximum viewing angle allowed by the vignetting of a non-zero width slitboard. In principle, the curve of image 730 may reach the slitboard.)

A further relation is that the slit width must vary inversely with the light brightness -- i.e., $D_s \propto 1/B$. In general, the device has higher resolution and less blur the smaller the slit width (analogously to how a pinhole camera has higher resolution with a smaller pinhole). Since smaller slits transmit less light, the brightness must increase with decreasing slit width in order that the same total amount of light reach viewer 30.

The width of slit 220 relative to the image width determines the amount of blur perceived by viewer 30 in the direction of motion. More specifically, the size of slit 220, projected from viewer 30 onto backboard 23, determines the scale over which the present device does not reduce blur. This length is set because the sliver of the image that can be seen through slit 220 at any given moment is in motion, and therefore blurred in the viewer's perception. The size of slit 220 relative to the image

width should thus be as small as practicable if the highest resolution possible is desired. In the parameter ranges of the two examples below, slit widths would likely be under about 0.03125 inch (under about 0.8 mm).

The achievable brightness and resolution, and their relationship, can be quantified.

First, define the following additional parameters:

$L_{ambient}$ = the ambient luminance of the viewer's environment

L_{device} = the luminance of the backboard on the apparatus

c = the contrast between the image and the ambient environment at the position of the viewer

$D_{vb} = D_{vs}+D_{bs}$ = the distance between the viewer and the backboard

$B_{ambient}$ = the brightness of the ambient environment at the position of the viewer

B_{device} = the brightness of the image at the position of the viewer

TF = the transmission fraction, or fraction of light that passes through the slitboard

R = the image resolution

$L_{ambient}$ describes the luminance of a typical object within the field of view of the viewer while looking at the image projected by the apparatus. This typical object should be representative of the general brightness of the viewer's environment and should characterize the background light level. For example, in a subway or train it might be the wall of the car adjacent to the window through which the apparatus is viewable.

$B_{ambient}$ is the brightness of that object as seen by the viewer, and

$$B_{ambient} = L_{ambient}/4\pi D_{ambient}^{2}, \qquad (6)$$

where $D_{ambient}$ is the distance between the viewer and the ambient object. It is sometimes difficult to select a particular object as representative of the ambient. As discussed above, in an embodiment used in a subway tunnel, the ambient object could be the wall of the subway car adjacent the window, in which case $D_{ambient}$ is the distance from the viewer to the wall. For ease of calculation, this may be approximated as D_{vs} because the additional distance from the window to the apparatus is relatively small.

L_{device} describes the luminance of the images on the backboard of the apparatus. Because the backboard is always viewed through the slitboard, which effectively filters the light passing through it, its brightness at the position of the viewer, B_{device} is

$$B_{device} = (L_{device}/4\pi D_{vb}^{2}) \times TF. \qquad (7)$$

TF, the transmission fraction of the slitboard, is the ratio of the length of slitboard transmitting light to the total length -- i.e.,

$$\begin{aligned} TF &= D_s/D_{ff} \\ &\leq (D_s \times D_{vs})/(D_i' \times D_{bs}), \qquad (8) \end{aligned}$$

where equality holds in the second line when $D_{ff} = D_i$.

R, the image resolution, is the ratio of the size of the image to the size of the slit projected onto the backboard,

$$\begin{aligned} R &= (D_i \times D_{vs})/(D_s \times D_{bs}) \\ &\approx D_i/D_s \\ &= (D_i' \times D_{bs})/(D_s \times D_{vs}) \qquad (9) \end{aligned}$$

This quantity is called the resolution because the image tends to blur in the direction of motion on the scale of the width of the slit. Because the eye can see the whole area of the image contained within the slit width at the same time, and the image moves in the

time it is visible, the eye cannot discern detail in the image much finer than the projected slit width. Therefore D_s effectively defines the pixel size of the image in the direction of motion. In other words, for example, if the slit width is one-tenth the width of the image, the image effectively has ten pixels in the direction of motion. In practice, the eye resolves the image to slightly better than R, but R determines the scale.

In order that the image meaningfully project a non-blurry image, R preferably is greater than 10, but this may depend on the image to be projected. It should also be noted that $R = 1/TF$ when $D_i = D_{ff}$, so that increasing the resolution decreases the transmitted light.

c is the contrast between the apparatus image and the ambient environment at the position of the viewer. In order that the image be viewable in the environment of the viewer, the apparatus brightness must be above a minimum brightness

$$B_{device} \geq B_{ambient} \times c. \qquad (10)$$

In order that the device be visible at all, c defines a minimum device brightness that depends on the properties of the human eye: if the device's image is too dim relative to its environment it will be invisible. The brightness of the device may always be brighter than the minimum defined by c. Practically speaking, c ought to be at least about 0.1. For many applications, such as commercial advertising, it may be desirable that c be greater than 1.

The following parameters comprise the smallest set of parameters (which may be referred to as "independent" parameters) that fully describe the apparatus according to the invention -- D_{vs}, D_{bs}, V_w, $L_{ambient}$, $D_{ambient}$, c, L_{device}, D_i, D_s, and D_{ff}. Other

parameters, which may be defined as "dependent parameters" are:

$D_i' = D_i \times D_{vs}/D_{bs}$

$D_{vb} = D_{vs}+D_{bs}$

$R = D_i/D_s$

$FR = V_w/D_{ff}$

$TF = D_s/D_{ff}$

$B_{ambient} = L_{ambient}/4\pi D_{ambient}{}^2$

$B_{device} = (L_{device}/4\pi D_{vb}{}^2) \times TF$

Of the independent parameters, the first five are substantially determined by the environment in which the apparatus is installed. In a subway system, for example, these five parameters are determined by the cross sections of the tunnel and train, the train speed, and the lighting in the train. On a pedestrian walkway or building interior, as another example, these parameters are determined by the dimensions of the walkway or hallway, pedestrian foot speed, and the ambient lighting conditions.

c and the dependent parameters R and FR are constrained by properties of human perception, and that the image of the apparatus be meaningful and not overly degraded by blurring. D_i' is constrained either by the environment (the width of a subway window, for example) or by the requirements of the image to be displayed by the apparatus (such as aesthetic considerations) or both. The remaining dependent parameters are determined by the independent parameters.

When these parameters are not substantially constrained, much greater leeway is allowed with the remaining four independent parameters, and the specific relationships set forth below need not be followed. Such relaxed conditions occur, for example, in connection with a surface train traveling outdoors in a flat environment when D_{vs} is largely unconstrained. Sometimes a substantially unconstrained parameter

results in an environment where the apparatus cannot be used at all, such as where the ambient light level varies greatly and randomly or the viewer speed is completely unknown.

The constraints on the remaining independent parameters are best expressed as a series of inequalities and are derived below.

Combining Relations 6, 7 and 10 provides the minimum slit width,

$$D_s \geq c \times (B_{ambient}/B_{device})(D_{bs} \times D_i')/D_{vs}$$

$$\geq c \times (L_{ambient}/L_{device})(D_{vb}^2/D_{ambient}^2)(D_{bs} \times D_i')/D_{vs} \qquad (11)$$

Solving Relation 9 for D_s gives,

$$D_s \leq (D_i' \times D_{bs})/(R \times D_{vs}). \qquad (12)$$

Combining Relations 11 and 12 constrains the slit width from above and below:

$$c \times (L_{ambient}/L_{device})(D_{vb}^2/D_{ambient}^2)(D_{bs} \times D_i')/D_{vs} \leq D_s \leq (D_i' \times D_{bs})/(R \times D_{vs}). \qquad (13)$$

In this relation, $L_{ambient}$ and all the distances except the slit width are substantially constrained by the environment, and R and c are constrained by properties of human visual perception. As discussed above, for ease of calculation, $D_{ambient}$ can be approximated by D_{vs}; note also that $(D_{bs} \times D_i')/D_{vs} = D_i$. The inequality between the far left and far right sides of the relation forces a minimum luminance for the apparatus, L_{device}. That is, if the luminance of the apparatus is below a minimum threshold, the apparatus image will be too dim to see in the brightness of the viewer's environment.

Once the luminance of the apparatus is sufficiently high, the inequalities between D_s and the far left and far right of the relation determine the allowable slit width range. A smaller slit width gives higher resolution but less brightness and a greater slit width gives brightness at the expense of resolution. A higher luminance of the apparatus

extends the lower end of the allowable slit width range.

Another similar relation for the frame-to-frame spacing may be derived from the relations above. Relation 3 may be written

$$D_{ff} \geq D_i \geq (D_i' \times D_{bs})/D_{vs}. \quad (14)$$

Relation 2, frame rate = V_w/D_{ff}, may be rewritten

$$D_{ff} \leq V_w/FR, \quad (15)$$

where FR denotes the frame rate and the equality has changed to an inequality to reflect that FR is a minimum frame rate necessary for the animation effect to work.

Combining Relations 14 and 15 yields,

$$(D_i' \times D_{bs})/D_{vs} \leq D_{ff} \leq V_w/FR. \quad (16)$$

V_w and all the distances except D_{ff} are substantially constrained by the environment, and FR is constrained by properties of human visual perception. Therefore the relation defines an allowable range for D_{ff}. It also puts a condition on the environments in which the present invention may be applied -- i.e., if the inequality does not hold between the far left and far right hand sides of the relation, the present invention will not be useful.

Choosing a lower D_{ff} puts second order frames closer to first order frames while improving the frame rate. Decreasing D_{ff} also increases the transmission fraction without decreasing the resolution. Choosing a higher D_{ff} moves the images farther apart at the expense of a reduced frame rate.

Though in principle apparatus 10 requires no included light source for its operation if ambient light is sufficient, such as outdoors (lid 21 or backboard 23 would have to be light-transmissive), in practice the use of very thin slits does impose such a requirement. That is, when operated under conditions

of low ambient light and desiring moderate resolution, bright interior illumination is preferable. The designation "interior" indicates the volume of the apparatus 10 between backboard 23 and slitboard 22, as opposed to the "exterior," which is every place else. The interior contains the viewable images 230, but otherwise may be empty or contain support structure, illumination sources, optical baffles, etc. as described above in connection with FIGS. 1, 2 and 2A.

Moreover, this illumination preferably should not illuminate the exterior of the device, or illuminate the viewer's environment or reach the viewer directly, because greater contrast between the dark exterior and bright interior improves the appearance of the final image. This lighting requirement is less cumbersome than that for stroboscopic devices -- in a subway tunnel environment, this illumination need not be brighter than achievable with ordinary residential/ commercial type lighting, such as fluorescent tubes. The lighting preferably should be constant, so no timing complications arise. Preferably the interior of apparatus 10 should be physically sealed as well as possible from the exterior subway tunnel environment as discussed above, preferably while permitting dissipation of heat from the light source, if necessary. The enclosure may also be used to aid the illumination of the interior by reflecting light which would otherwise not be directed towards viewable images 230.

Two examples show in more detail how the various parameters interrelate.

<u>Example 1</u>

The first example illustrates how all constraints tend to relax as V_w increases. For

example, in a typical subway system the following parameters may be imposed:

$V_w \approx 30$ mph (train speed)

$D_{bs} \approx 6$ inches (space between train and wall)

$D_{vs} \approx 6$ feet (half the width of a train, for the average location of a viewer 30 within the car)

$D_i' \approx 3$ feet (width of train window)

By Relations (3) and (1),

$$\begin{aligned} D_{ff} &\geq D_i \\ &\geq (D_i' x D_{bs})/D_{vs} \\ &\geq (3 \text{ ft} \times 0.5 \text{ ft})/6 \text{ ft} \\ &\geq 0.25 \text{ feet.} \end{aligned} \tag{17}$$

If the images are abutted so that $D_{ff} = D_i$, the maximum frame rate is attained. Then, by Relation (2),

$$\begin{aligned} \text{Frame rate} &= 30 \text{ mph}/0.25 \text{ ft} \\ &= 176 \text{ frames per second.} \end{aligned} \tag{18}$$

At this rate the parameters can be adjusted a great deal while still maintaining high quality animation. This frame rate is also high enough to support interlacing of images (see above) if desired, despite the reduction in effective frame rate that results from interlacing.

<u>Example 2</u>

The second example illustrates how the constraints tighten when near the minimal frame rate. To find the lowest practicable V_w, assume the following parameters:

frame rate $\approx$ 20 frames/sec

$D_{bs} \approx 6$ inch

$D_{vs} \approx 6$ feet

$D_i' \approx 2$ feet.

By Relation (1),

$$\begin{aligned} D_i &= (D_{bs} \times D_i')/D_{vs} \\ &= (0.5 \text{ ft} \times 2 \text{ ft})/6 \text{ ft} \end{aligned}$$

$= 2$ inches.

For abutted images, $D_{ff} = D_i$, and,

$$V_w = D_{ff} \times \text{frame rate}$$
$$= 2 \text{ inches} \times 20 \text{ frames/sec}$$
$$= 40 \text{ inches/sec},$$

which is approximately pedestrian footspeed.

The implication of this last result -- that the device can successfully display quality animations to pedestrian traffic -- vastly increases the potential applicability of this device relative to stroboscopically based arrangements.

The following alternative exemplary embodiments are within the spirit and scope of the invention.

FIG. 8 illustrates another exemplary embodiment 80 altering the optimal viewing angle of the animation. In apparatus 80, backboard 83 bears images 830 that are inclined at an acute angle to backboard 83, varying the viewing angle from a right angle to that acute angle. This alteration permits more natural viewing for a pedestrian, for example, by not requiring turning of the pedestrian's head far away from the direction of motion. This embodiment may also eliminate second order images.

FIG. 9 illustrates a further exemplary embodiment 90 similar to apparatus 80, but in which slitboard 92 is also angled. This refinement again provides a more natural viewing position for a pedestrian. The asymmetric triangular design permits natural viewing for viewers moving from left to right. A symmetric design (not shown), in which the plan of the slitboard might more resemble, for example, a series of isosceles triangles, could accommodate viewers moving in both directions.

FIG. 10 illustrates a technique of using one slitboard 101 as the backboard of a different slitboard 102, while simultaneously using that slitboard 102 as the backboard of the original slitboard 101. This configuration permits the back-to-back installation of two devices in the space of one. This apparatus 100 may be improved by offsetting one set of slits from the other by $D_i/2$, or some fraction of D_i.

FIG. 11 shows a simple schematic plan view of apparatus 100. Slits 220 of one slitboard 101 are centered between slits 220 of the opposite slitboard 102, which is acting as the former slitboard's backboard. That is, between slits 220 of one slitboard are images 230 viewable through the other slitboard, and vice-versa. Because the slits are very thin, their presence in the backboard creates negligible distraction.

FIG. 12 shows another embodiment 120 similar to apparatus 100, but having a set of curved images 1230 (as in FIG. 7) facing slits 220 of opposite slitboards/backboards 101, 102. Apparatus 120 thus has characteristics, and advantages, of both apparatus 70 and apparatus 100.

FIG. 13 illustrates a roller type of image display mechanism 130 that may be placed at the position of the backboard. The rollers may contain a plurality of sets of images that can be changed by simply rolling from one set of images to another. Such a mechanism allows the changing of images to be greatly simplified. In order to change from one animation to another, instead of manually changing each image, one may roll such rollers to a different set of images. This change could be performed manually or automatically, for instance by a timer. By

incorporating slits 220, mechanism 130 can be used in apparatus 100 or apparatus 120.

Yet another exemplary embodiment 140 is shown in FIGS. 14 and 15. In apparatus 140, "backboard" 141, with its images 142, is placed between viewer 30 and a series of mirrors 143. Each mirror 143 preferably is substantially the same size and orientation as any slits that would have been used in the aforementioned embodiments. Mirrors 143 preferably are mounted on a board 144 that takes the place of the slitboard, but mirrors 143 could be mounted individually or on any other suitable mounting. The principles of operation of apparatus 140 are substantially the same as those for the aforementioned embodiments. However, because "backboard" 141 would obscure the sight of mirrors 143 by viewer 30, "backboard" 141 may be placed above or below the line of sight of viewer 30. As shown in FIGS. 14 and 15, "backboard" 141 is above the line of sight of viewer 30. As drawn in FIGS. 14 and 15, moreover, both "backboard" 141 and "mirrorboard" 144 are inclined. However, with proper placement, inclination of boards 141, 144 may not be necessary. As in the case of a slitboard, "mirrorboard" 144 will work best when its non-mirror portions are dark, to increase the contrast with the images.

A complete animation displayed using the apparatus of the present invention for use in a subway system may be a sizable fraction of a mile (or more) in length. In accordance with another aspect of the invention, such an animation can be implemented by breaking the backboard carrying the images for such an animation into smaller units, providing multiple apparatus according to the invention to match the local design of the subway tunnel structure where feasible. Many subway systems have repeating support structure along the length of a tunnel to which such modular

devices may be attached in a mechanically simplified way.

As an example, the New York City subway system has throughout its tunnel network regularly spaced columns of support I-beams between many pairs of tracks. Installation of apparatus according to the present invention may be greatly facilitated by taking advantage of these I-beams, their regular spacing, and the certainty of their placement just alongside, but out of, the path of the trains. However, this single example should not be construed as restricting the applicability to just one subway system.

The modularization technique has many other advantages. It has the potential to facilitate construction and maintenance, by taking advantage of structures explicitly designed with the engineering of the subway tunnels in mind. The I-beam structure is sturdy and guaranteed not to encroach on track space. The constant size of the I-beams consistently regulates D_{bs}, easing design considerations. Additionally, cost and engineering difficulties are reduced insofar as the apparatus may be easily attached to the exterior of the supports without drilling or possibly destructive alterations to existing structure.

FIG. 16 schematically illustrates an example of the modularization possible for the two-sided apparatus of FIGS. 10 and 11. As shown, construction of the whole length of two slitboards, which could be a half mile or more in length, is reduced to constructing many identical slitboards 160, each about as long as the distance between adjacent I-beam columns 161 (e.g., about five feet). Each of the slitboards is then attached to a pair of the existing support I-beams, along with the other parts of the apparatus as described above.

FIG. 17 shows a preferred embodiment of a single unit of display apparatus in accordance with the present invention. Single-unit display apparatus 1700 includes two images 1730A and 1730B mounted on a surface of backboard 1723. Images 1730A and 1730B correspond to a single slit 1720 of slitboard 1722, and each belongs to a different series of images (e.g., an A series and a B series). Each series of images independently projects at a respective viewing angle a separate animation to viewers moving along the same trajectory. These separate animations can be the same or different. Apparatus 1700 is especially advantageous in spatially constrained environments because two animations can be projected from a single display apparatus.

Each series of images can be advantageously arranged to project separate animations to viewers moving along a trajectory in either the same direction or opposite directions. For example, if both the A and B series of images are arranged in a forward sequence relative to each other (e.g., A1, B1, A2, B2, A3, B3, etc.), viewers moving in the same direction can see one animation at one viewing angle (i.e., along one line of sight) and a second animation at a second viewing angle (i.e., along a second line of sight). This is shown in FIG. 18 where pedestrians 1801 and 1802 are both walking in direction 1803 on walkway 1805, which is substantially parallel to apparatus 2300 (shown in more detail in FIG. 23). Pedestrian 1802 can see one animation when gazing at apparatus 2300 along line of sight 1807, and pedestrian 1802 can see a second animation when gazing at apparatus 2300 along line of sight 1808.

Conversely, if the B images are arranged in a reverse sequence relative to the A images (e.g., A1, Bn, A2, Bn-1 . . . An-1, B2, An, B1), viewers moving in

opposite directions can each see separate animations. This is shown in FIG. 19 where pedestrian 1901 walking in direction 1903 can see one animation when gazing at apparatus 2200 (shown in more detail in FIG. 22) along line of sight 1907, while pedestrian 1902 walking in the opposite direction 1904 can see a second animation when gazing at apparatus 2200 along line of sight 1908.

FIG. 20 shows a schematic plan view of apparatus 1700 in which A-B images are preferably arranged in a reverse sequence relative to each other. A first viewer gazing through slit 2020 along line of sight 2001 can see the center of image 2030B, while a second viewer gazing through slit 2020 along line of sight 2002 can see the center of image 2030A. The widths of images 2030A and 2030B are preferably equal, but they need not be. Images 2030A and 2030B are preferably placed side-by-side with their common boundary aligning with slit 2020 along normal line 2011. This symmetry and boundary alignment are also not required, as illustrated in other embodiments described below. Viewing angles α and β are each measured from normal line 2011 and while equal to each other in this embodiment, they need not be, because viewing angles can be selected by design, as also described below. For this embodiment, viewing angles α and β are also selected such that they approximately equal the ratio of half the image width to the distance between backboard 2023 and slitboard 2022. While other parts of images 2030A and 2030B can be seen from angles other than α and β, optimal viewing of each projected animation is at angles α and β (i.e., along lines of sight to the image centers).

The present invention is not limited to projecting only two series of images (i.e., apparatus having two images per slit). In principle, the present

invention can have an arbitrary number of images per slit, projecting an arbitrary number of animations. For example, a single unit of display apparatus 2100, shown in FIG. 21, includes four images 2130A-D per slit 2120 in accordance with the present invention. Each image 2130A-D can be seen when viewed along that image's associated line of sight (each of which is at a different viewing angle measured from normal line 2111). For example, image 2130A can be seen when viewed along line of sight 2102 and image 2130B can be seen when viewed along line of sight 2104.

The number of images per slit, however, is limited by practical considerations. For example, a primary consideration is viewer speed relative to the apparatus -- more images per slit generally increases the frame-to-frame distance, which decreases the frame rate. Frame rates less than 15 frames per second result in poor animation and should therefore be avoided. If image widths are decreased to compensate for the increased frame-to-frame distance, the resolution of the projected image, which is roughly equal to the ratio of the slit width to the image width, will decrease. If the resolution is increased by decreasing the slit width, less light will be transmitted through the slitboard, thus requiring brighter illumination. This may increase heat dissipation and operational costs. Also, more precise machining (e.g., laser cutting) may be required to form the narrower slits. This may increase manufacturing costs. Other considerations may also limit the number of images per slit.

FIG. 22 is a schematic plan view of a section of apparatus 2200 in accordance with the present invention. Apparatus 2200 has two images per slit in which the B series of images is arranged in a reverse sequence relative to the A series of images. Thus, a

viewer moving from left to right can see animation of images 2230A1-A4 when viewing apparatus 2200 along lines of sight 2201, 2203, 2205, and 2207. A viewer moving from right to left can see animation of images 2230B1-B4 when viewing apparatus 2200 along lines of sight 2202, 2204, 2206, and 2208.

Alternatively, the A and B series of images can be both arranged in a forward sequence relative to each other. FIG. 23 shows a schematic plan view of a section of apparatus 2300 having such an arrangement of images in accordance with the present invention. A viewer moving from left to right can see animation of images 2330A1-A4 when viewing apparatus 2300 along lines of sight 2301, 2303, 2305, and 2307. A viewer also moving from left to right can see animation of images 2330B1-B4 when viewing apparatus 2300 along lines of sight 2302, 2304, 2306, and 2308. Note that viewers moving from right to left can also see animation of the A or B images (depending on their lines of sight), but in reverse sequence (i.e., the animations will appear to be running backwards). Thus, apparatus 2300 is applicable to environments with preferably one-way traffic.

Note that the aforementioned image sequences are merely illustrative, and should not be construed as limiting the invention to only those sequences. Other image sequences are possible. For example, in some applications an image series such as A1, A1, B1, A2, A2, B2, A3, A3, B3, etc. may be desirable.

The principles of operation and the dimensioning of apparatus having multiple series of images are substantially similar to that of apparatus having single images per slit, such as, for example, apparatus 10 of FIGS. 1, 2, and 3. However, the positioning of each image of each series relative to the same slit is more complex because of the number of

image orders (e.g., first, second, and third) of each series of images (e.g., A and B series) that are viewable through each slit. Referring to FIG. 22, for example, lines of sight 2201-2208 are referred to as first-order lines of sight because image series 2230A1-A4 and 2230B1-B4 are the closest to and preferably the only images seen respectively through slits 2220i-v. (Similarly, lines of sight 2301-2308 of FIG. 23 are also referred to as first-order lines of sight.) In reality, however, a viewer may be able to see at slightly different viewing angles other orders of the same series as well as orders of other series. For example, while images A1-A4 are the intended images to be seen through respective slits 2220i-v of apparatus 2200 when moving from left to right, a viewer may also be able to see the B series in reverse sequence (i.e., B4-B1). Moreover, a viewer may also be able to see non-first order images of the A series. For example, a viewer may also be able to see images 2230A1 and 2230A3 in addition to image 2230A2 when looking through slit 2220ii. That viewer may also be able to see non-first order B-series images (running backwards). Such projected images will likely appear as a series of television screens with alternating programs.

Explained another way, animation of the A-series images can be seen along first-order lines of sight 2201, 2203, 2205, and 2207. To the right of that animation will be the animation of the B-series images running backwards in time (because the B images are in a reverse sequence relative to the A images). To the right of that B-series animation will be a second-order A-series animation -- that is, animation of the A series slightly offset in time relative to the first-order A-series animation. To the right of that second-order A-series animation will be the next

B-series animation, also running backwards and offset in time relative to the previous B-series order. The sequences of A forward and B backward continue until the viewer's line of sight for that slit is cutoff by slitboard 2222. Note that the same multiple animation effect can be observed with respect to apparatus 2300, except that the B-series animations will not be running backwards (because the A and B images are both sequenced the same relative to each other).

Another consideration regarding apparatus having two series of images is that viewing angles (e.g., angles α and β of FIG. 20) are typically very small for first-order images. First-order images appear at almost 90° with respect to a viewer's direction of motion. While such a viewing angle may be preferable for a viewer traveling in a subway train, for example, such a viewing angle is not preferable for pedestrians who could be inconvenienced or injured while looking almost 90° from their direction of motion. Another disadvantage of such small viewing angles is that from a viewer's perspective, only a small spatial separation exists between the two series of images.

Advantageously, viewable multiple orders of images and the effects of small viewing angles can be overcome in accordance with the present invention. One solution is to increase the spacing between adjacent images, as shown by a section of display apparatus 2400 in FIG. 24. Such increased spacing D_s, however, increases the frame-to-frame distance, which decreases the frame rate. To compensate, other parameters can be adjusted. For example, if the backboard to slitboard distance is decreased, the increased stretching effect allows a smaller image width, which decreases the frame-to-frame distance, thus increasing the frame

rate. This may also involve adjustments to other parameters

Another more preferable solution is to select another order image to be viewed through each slit and to accordingly limit the lines of sight to preferably only those images of the selected order. For example, a more comfortable (and safer) viewing angle for a pedestrian may result from viewing a higher order image, such as, for example, image 2530A4 viewed along line of sight 2501 through slit 2520i, as shown in FIG. 25. If D_{ff} is about half of D_{bs}, then image 2530A4 is viewable at an angle of about 60° measured from a line normal to backboard 2523. Thus a pedestrian need only look about 30° from that pedestrian's direction of motion to see fourth order animation. Lines of sight to all other orders of images preferably should be blocked. While this can be easily accomplished using baffles in apparatus having a single image per slit, apparatus having multiple images per slit presents the difficulty of restricting one viewer's lines of sight to undesired orders of images without restricting another viewer's lines of sight to a desired order of images.

FIGS. 26 and 27 are schematic plan views of a section of apparatus 2200 illustrating selected ranges of lines of sight 2601-2608 and 2701-2706 that should not be blocked in order that viewers be able to view selected higher order A-series and B-series animations. As shown, a viewer moving from left to right can view either a second order (FIG. 26) or third order (FIG. 27) A-series animation. Similarly, a viewer moving from right to left can view either a second order (FIG. 26) or third order (FIG. 27) B-series animation. To preferably prevent or at least limit viewers from viewing other images, regions 2609-2613 and 2709-2712 should be blocked.

FIG. 28 shows an exemplary embodiment of a section of display apparatus in accordance with the present invention. Apparatus 2800 includes opaque elements 2809-2815 positioned between slitboard 2822 and backboard 2823. Opaque elements 2809-2815 preferably block regions through which viewers would otherwise be able to view unintended images. In other words, opaque elements 2809-2815 preferably limit lines of sight to only those images that are intended to be seen by viewers. Alternatively, apparatus 2800 may still produce satisfactory animations with less than all opaque elements 2809-2815. For example, satisfactory animation may still be produced if only opaque elements 2809-2811 or opaque elements 2812-2815 are used.

FIG. 29 shows a preferred embodiment of a section of display apparatus in accordance with the present invention. Apparatus 2900 uses baffles to block regions that viewers preferably should not see through. Baffles 2909-2911 effectively perform the same function as opaque elements 2809-2815, but are generally easier and less costly to produce and install. Baffles 2909-2911 are positioned substantially parallel to, and between, slitboard 2922 and backboard 2923, and can be constructed as a third substantially parallel board. The sides of baffles 2909-2911 facing slitboard 2922 are preferably both non-reflective and dark to increase the contrast with the animations. The sides of baffles 2909-2911 facing backboard 2923 are preferably white, light colored, or reflective to increase the amount of light illuminating the images mounted on backboard 2923.

Baffles also can be constructed for apparatus in which viewers moving in the same direction are preferably limited to particular lines of sight for each series of images, as shown, for example, by a

section of apparatus 3000 in FIG. 30. Baffles 3009-3017 preferably block most unintended lines of sight while permitting views along lines of sight 3001-3008 to selected orders of A and B series images.

Other baffle arrangements also can be used to block unintended lines of sight. For example, a row of baffles corresponding to opaque elements 2812-2815 can be used in addition to or instead of baffles 2909-2911. Generally, multiple sets of planar baffles can replace multiple sets of opaque elements, and vice versa. Furthermore, any combination of planar or non-planar baffles can be used to block designated regions.

In particular, "T-shaped" baffles can be very effective in limiting lines of sight to only intended images. For example, while many lines of sight to unintended image orders are blocked in apparatus 2900 and 3000, it may still be possible to see unintended image orders to the extreme right or left of an intended image (e.g., in apparatus 2900, it may be possible to see image 2930B1 through slit 2920i in addition to intended image 2930A2). This can be prevented by installing T-shaped baffles 3109-3111 as shown in FIG. 31. Similarly, unintended images orders still viewable in apparatus 3000 can be blocked using either T-shaped baffles 3211A, 3213A, 3215A, and 3117A as shown in FIG. 32A, T-shaped baffles 3211B, 3213B, 3215B, and 3217B as shown in FIG. 32B, or a combination of both. Alternatively, the vertical section of a T-shaped baffle need not be at a right angle to the horizontal section.

Note that while it is possible to select image orders higher than those described above (i.e., higher than the first order of FIGS. 22 and 23, second order of FIG. 26, third order of FIG. 27, and fourth order of FIG. 25), such selection of higher orders of images results in a higher number of regions of smaller

angular size that should be blocked to prevent unintended orders of images from being viewed. Thus, selecting higher orders of images and accordingly attempting to limit views to them requires increasingly more precision and is therefore less practical the higher the order selected.

FIG. 33 shows another preferred embodiment of a section of display apparatus in accordance with the present invention. Display apparatus 3300 includes lighting 3327, which may be standard light bulbs or fluorescent tubes, for example. Lighting 3327 is placed between baffles 3309-3311 and backboard 3323 such that the images are illuminated without directly illuminating viewers. Lighting 3327 can also be used similarly with apparatus 3100, 3200A, and 3200B.

Advantageously, apparatus having spaced apart adjacent images, such as, for example, apparatus 2400, also can include lighting, opaque elements or baffles, or both in accordance with the present invention.

Moreover, many of the other embodiments of apparatus described above, such as, for example, the curved apparatus shown in FIG. 3A, apparatus 100, apparatus 140, and the modularized apparatus shown in FIG. 16, can advantageously include multiple images per slit. Roller image display mechanism 130 also can be used in apparatus having multiple images per slit. Furthermore, apparatus having multiple images per slit can alternatively include a light source positioned behind a light transmissive backboard, similar to, for example, apparatus 200.

Thus it is seen that display apparatus for use in spatially-constrained environments are provided that display multiple series of still images such that each series appears animated to viewers in motion relative to the apparatus. One skilled in the art will appreciate that the present invention can be practiced

by other than the described embodiments, which are presented for purposes of illustration and not of limitation, and the present invention is limited only by the claims which follow.